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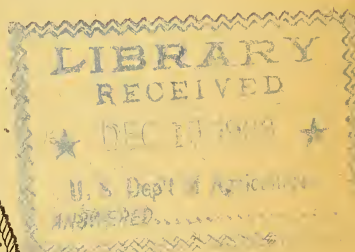
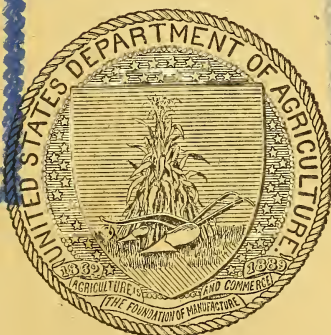
OFFICE OF EXPERIMENT STATIONS—BULLETIN 202.

A. C. TRUE, Director.

DIGESTIBILITY OF STARCH OF DIFFERENT
SORTS AS AFFECTED BY COOKING.

BY

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WASHINGTON:

GOVERNMENT PRINTING OFFICE.

1908.

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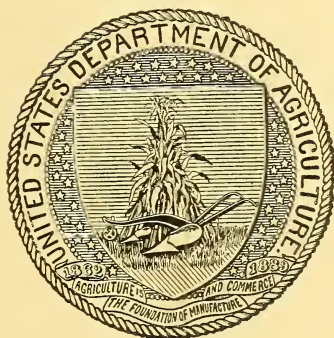
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THE OFFICE OF EXPERIMENT STATIONS.

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(2)

[Bull. 202]

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF EXPERIMENT STATIONS,
Washington, D. C., July 15, 1908.

SIR: I have the honor to transmit herewith and recommend for publication as Bulletin 202 of this Office a report of investigations on the digestibility of starch of different sorts as affected by cooking, conducted by Miss Edna D. Day, at the laboratory of physiological botany of the University of Michigan, and later at the University of Illinois and at the laboratories of physiological chemistry and plant physiology of the University of Chicago.

The investigations were planned in such a way as to supplement the investigations on the changes brought about in food products by different cooking processes, which have been carried on as a part of the cooperative nutrition investigations of this Office, and during the work Miss Day was in consultation with the Director and his associates having charge of the details of the nutrition investigations.

Of special interest and importance from the housekeeper's standpoint is Miss Day's conclusion that at least in the case of starch itself long continued cooking is not necessary, since it increases digestibility only slightly and out of proportion to the time and trouble involved, though with cornstarch an improvement in flavor was noticed after thirty to forty minutes' cooking. In solving culinary problems the changes brought about in other constituents usually associated with starch in foods must, however, be taken into account.

Acknowledgment should be made to Prof. F. C. Newcombe, of the University of Michigan; to Dr. Charles Hottes, of the University of Illinois, and to Profs. Marion Talbot, A. P. Mathews, and Charles R. Barnes, of the University of Chicago, as well as to Dr. H. McGuigan and Dr. H. Hasselbring, of the same institution.

Respectfully,

A. C. TRUE, *Director.*

HON. JAMES WILSON,
Secretary of Agriculture.

CONTENTS.

	Page.
Introduction.....	7
Materials, apparatus, and methods used in experimental work.....	17
Experiments on the effect of cooking starch.....	22
Experiments with raw starch.....	22
Digestion experiment No. 1.....	23
Digestion experiment No. 2.....	24
Digestion experiment No. 3.....	24
Experiments with starch cooked below the boiling temperature.....	25
Digestion experiment No. 4.....	26
Digestion experiment No. 5.....	28
Experiments with starch boiled five minutes.....	30
Digestion experiments Nos. 6 and 7.....	30
Experiments with starch boiled more than five minutes.....	30
Digestion experiment No. 8.....	31
Digestion experiment No. 9.....	31
Digestion experiment No. 10.....	31
Digestion experiment No. 11.....	32
Digestion experiment No. 12.....	32
Digestion experiment No. 13.....	32
Digestion experiment No. 14.....	33
Experiments with starch cooked in a water bath or double boiler.....	34
Digestion experiment No. 15.....	34
Experiments on the digestibility of starch by different diastases.....	34
Digestion experiment No. 16.....	34
Digestion experiment No. 17.....	35
Experiments on the digestibility of different preparations of the same kind of starch.....	35
Digestion experiment No. 18.....	35
Digestion experiment No. 19.....	36
Digestion experiment No. 20.....	36
Additional attempts to identify rose amylose in potato starch.....	37
Digestion experiment No. 21.....	37
Digestion experiment No. 22.....	37
Digestion experiment No. 23.....	37
The possibility of reversion in wheat and corn starches.....	38
Digestion experiment No. 24.....	38
Experiments on the digestibility of tapioca, sago, pearled barley, and rice starch.....	38
Digestion experiment No. 25.....	39
Cornstarch <i>v.</i> wheat starch.....	39
Deductions and conclusions.....	39

ILLUSTRATIONS.

	Page.
FIG. 1. Diagram representing Meyer's theory of a four-layered starch grain ..	9
2. A potato starch grain of large size magnified 385 times	10
3. Raw starch grains magnified 385 times	22
4. Raw starch grains that have been digested 38 hours	23
5. Potato starch magnified 87 times, showing successive stages in paste formation	25
6. Starch grains from unboiled pastes	26

THE DIGESTIBILITY OF STARCH AS AFFECTED BY COOKING.

INTRODUCTION.

The digestion of starch has been studied from various standpoints and by many investigators, but the subject still offers opportunities for investigation. Thus, it has been studied with reference to the characteristics of enzym activity; it has been studied as a means to knowledge of the composition of the starch molecule, and it has been studied from the standpoint of plant and of animal nutrition; but a search through the literature of the subject leads to the conclusion that it has been very little studied for the purpose of helping solve the housekeeper's problem of how starchy foods may best be prepared for every day human digestion.

As starch, next to water, is the substance most abundantly present in food, a knowledge of the effect of cooking on its digestibility is desirable, both from a practical and a scientific standpoint. The following comparative study of the relative digestibility of different forms of starch—uncooked, cooked below boiling temperature, and boiled for short and long periods of time—is presented as a contribution to this large subject.

A brief summary of current theories bearing on the subject may fitly precede a report of these investigations, and it is believed such a summary will be helpful to the student of starch who has found theories varied and conflicting. It will certainly be helpful in understanding the results of the experiments here recorded and in judging of the validity of the conclusions reached.

The empirical knowledge, gained by generations of experience in cooking and eating starchy foods, first deserves attention. Judging from popular traditions among housekeepers, such experience teaches that (1) raw starch is indigestible or at least relatively so; (2) to be made easy of digestion starch should be cooked at boiling temperature or higher; (3) after the starch has once been brought to the boiling point its cooking may be continued at a somewhat lower temperature, as, for instance, in the double boiler; (4) in general, the longer starch is cooked the better; (5) in cooking starch lumps

should be avoided; (6) cornstarch needs longer cooking than does wheat starch; (7) of the two starchy foods, rice and potatoes, rice is more easily digested than potato, and (8) French cooks believe that potato starch has better culinary properties than cornstarch or wheat starch (flour) in thickening sauces and gravies.

Next to housekeepers, those most interested in this problem have been physicians, and statements from text-books on physiological chemistry follow:

"The individual grain [of starch] is inclosed in a capsule of so-called starch cellulose which is insoluble in water but which can be made to open by heating in the presence of much water. The contained starch granulose can thus be obtained."^a

Another writer^b states that according to ordinary opinion, starch grains consist of two different substances, starch granulose and starch cellulose, of which the first only goes into solution on treatment with diastatic enzymes. Starch is practically insoluble in cold water. In warm water the grains swell up and burst, yielding a paste. Boiled starch is quickly, and unboiled starch very slowly, converted into sugar. Various kinds of unboiled starch are converted with different degrees of rapidity.

This theory of the outer, indigestible layer of the starch grain gives a reason for cooking starch, but it suggests no value in long cooking. It is the old theory of Nägeli,^c published in 1858, without even the modification made by Brown and Heron^d in 1879. Brown and Heron taught that starch cellulose formed the outer layer of the starch grain and that, unless it was broken mechanically, as by grinding with glass, or dissolved by cytase, as in the plant cell, it prevented entirely the digestion of raw starch. However, they found that, if the starch was made into a thin paste and treated with plenty of malt extract at a temperature above 45° C., the outer layer as well as the inner parts was entirely digested.

But the botanists tell us that the theory of the outer layer of starch cellulose has been out of date with them for twelve years, and point to Arthur Meyer's^e studies of starch grains as authority for this statement. As a result of his work he offers a theory of starch composition which is generally accepted by botanists to-day, which in brief is as follows: Starch grains are sphero-crystals, i. e., they are more or less regular spheres composed of a mass of radiating needle-shaped crystals, which he calls trichites.^f

^a C. Simon. *A Text-Book of Physiological Chemistry*. Philadelphia, 1904, p. 73.

^b O. Hammarsten. *Lehrbuch der Physiologischen Chemie*. Wiesbaden, 1907, pp. 126 and 346.

^c *Die Stärkekörner*. Zurich, 1858.

^d *Jour. Chem. Soc. [London]*, 35 (1879), pp. 596-654.

^e *Untersuchungen über die Stärkekörner*. Jena, 1895.

^f *Ibid.*, pp. 100-129.

Figure 1, which is redrawn from Meyer's report,^a represents diagrammatically his theory of the structure of a starch grain having four concentric layers. Figure 2 shows the microscopic appearance of a normal potato starch grain showing 20 layers, magnified 385 times. A comparison of the two will give an idea of the very small size of these trichites.

The layers, he believes, are successively deposited one outside of the other, beginning with the hilum or point of origin. He suggests that the difference in appearance of the different layers is due to a difference in the size of the trichites and to a difference in the amount of space between them, as shown in the figure. This, he believes, is due to alternating differences in growth conditions in the plant cell in which the grain was formed, the loose layers being formed by partial solution, at the surface, during the night, of the starch deposited during the previous day.^b

The outer layer he regards as no different from the others except that in some cases it is more dense, due to the fact that the starch is gathered after the end of the growth period in the plant, and the last growth is slower than the first.^c

Some of these trichites, according to his theory, are composed of α -amylose and some of β -amylose.^d They are both present in every layer though perhaps in different proportions.^e In some grains part of the trichites are composed of amyloextrin.

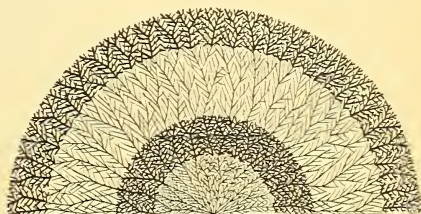


FIG. 1.—Diagram representing Meyer's theory of a four-layered starch grain. (From his *Untersuchungen über die Stärkekörner*, p. 107.)

Meyer's β -amylose corresponds in properties to the starch granulose of earlier writers. It stains blue with iodine and is easily digestible. It is insoluble in cold water.^f In hot water (60° to 80° C.) Meyer believes that the trichites absorb water and swell to a spherical form, and that the ordinary starch paste is an emulsion of these tiny sticky droplets.^g At 138° C. he says that they go into solution in water, producing a clear liquid.

When a starch paste is exposed to dry air, a skin forms on the surface. Meyer says that this is due to the sticking together of these viscous swollen β -amylose trichites, and that they can scarcely be separated again by shaking in hot water.^h

His α -amylose corresponds in a measure to the starch cellulose or amylocellulose of others. He says that it differs from β -amylose in

^a *Untersuchungen über die Stärkekörner*.
Jena, 1895, p. 107.

^b *Ibid.*, pp. 242-248.

^c *Ibid.*, p. 133.

^d *Ibid.*, pp. 1 and 2.

^e *Ibid.*, p. 116.

^f *Ibid.*, pp. 14-27.

^g *Ibid.*, p. 130.

^h *Ibid.*, p. 13.

lacking water of crystallization. These α -amylose trichites absorb boiling water very slowly. In water at 138° C. they go into a solution in every respect like that of β -amylose. With iodine solution the solid form stains a faint red color. The solution gives the usual blue. The solid is digested very slowly; its solution very rapidly.^a



FIG. 2.—A potato starch grain of large size, magnified 385 times: *a*, hilum or point of origin.

In starch grains of different kinds α -amylose is present in different amounts. He reports 0.6 per cent in potato starch, 0.9 per cent in rice, 1 per cent in corn, 1.5 per cent in wheat, and 2.5 per cent in arrowroot.^b The amount obtained from the same kind of starch grain he found differed with the method used to isolate it. He obtained 0.7 to 13 per cent from the same sample of potato starch.^c This is one reason he gives for believing that α -amylose is easily convertible into β -amylose, and that the two are essentially one substance.

Amylodextrin is a term that has been used by different writers to designate different substances. Meyer uses it to name the substance which is a first stage in the digestion of starch in the cold with acid, and which stains red with iodine. It is slowly soluble in cold water and readily in warm water. It is easily changed by further digestion to sugar.^d

There are some starch grains that stain red instead of blue with iodine. From them Meyer claims to have extracted amylodextrin. Sometimes he has seen a red color in starch grains which generally stain blue and he considers the color due to amylodextrin formed by some digestive process.^e

Contrary to the experiences of Brown and Heron, Meyer reports that unbroken raw starch grains can be digested by both malt extract and saliva. This is quite in accord with his theory of a porous starch grain (see fig. 1), any part of which can be penetrated by enzymes without a preliminary breaking of an outer wall. He explains the very slow digestion of raw starch by saying that since the pores are of less than microscopic size, diffusion inward of enzymes and outward of digestion products takes place very slowly. He finds the grains that show cracks are much more quickly digested raw than are solid grains. But with either the solid or more or less cracked grain the surface exposed is very small in comparison with that of an equal quantity of starch substance in the form of a paste.^f

According to Meyer, then, starch is very slowly digested in the raw form; quickly but not completely if it has been made into a paste

^a Untersuchungen über die Stärkekörner. Jena, 1895, pp. 13, 14.

^b Ibid., p. 9.

^c Ibid., p. 5.

[Bull. 202]

^d Ibid., pp. 27–39.

^e Ibid., p. 82.

^f Ibid., p. 24.

with water from 60° to 80° C. (140° to 176° F.), and quickly and completely if it has been cooked a long time or heated to 138° C. There is nothing in his theory to justify the cook's insistence on the boiling temperature, nor is there warrant for cooking cornstarch longer than wheat starch, since he reports that the latter contains more α -amylose than the cornstarch. Moreover, arrowroot starch, which physicians often recommend for invalids and young children as especially easy of digestion, he finds has more α -amylose than either corn or wheat starch.

In his book, Meyer reviews and criticises in the light of his own extensive observations and experiments the earlier investigations on the subject. Since its publication in 1895 several hundred articles have been published in scientific journals on the subject of starch, but only a few of these need be mentioned here. The theory of the sphero-crystalline form of the starch grain seems to be generally accepted by those who are familiar with it.

Kraemer^a seems to be the only botanist who has recently insisted that the outer layer of the starch grain is different from the other layers. He suggests that it may be an anhydrid of starch cellulose.

In 1897 Bütschli^b described some artificial starch grains precipitated from solutions of starch either by evaporation or freezing. He said also that the skin that forms on starch paste on standing, which Meyer considers due to the sticking together of swollen α -amylose trichites, is of the same nature as the precipitated starch, and that they are both harder of solution and digestion than raw starch.

In 1899 Rodewald and Kattein^c reported the formation of artificial starch grains in starch solutions made by heating starch with iodine at 130° C.

Recently (1903-1907) four associated scientists, A. Fernbach, E. Roux, L. Maquenne, and J. Wolff, have given considerable attention to this reversion of starch. They report that a clear aseptic solution of starch prepared by heating in an autoclave to 130° C. passes, on cooling, through a series of retrogressive changes. It first becomes like ordinary starch paste, in which form it is easily digested. From this form it passes by degrees into a final form, which they call amylocellulose. The characteristics of this form are that it gives no color with iodine and is difficult both of solution in boiling water and of digestion by diastase. Furthermore, on treating with potassium hydroxid or by heating again with water to 130° it dissolves, forming

^a Bot. Gaz., 34 (1902), pp. 341-354.

^b Verhandl. Naturhist. Med. Ver. Heidelberg, 5 (1897), pp. 457-472.

^c Sitzungsber. d. Berl. Acad., 33 and 34 (1899), p. 628.

a solution that colors blue with iodine but that does not gelatinize on cooling as does starch paste.^a

They also report that the same reverted starch or amylocellulose is formed if starch pastes are liquefied by the first stages of digestion and then the digestive process checked.^b This suggests the description given by Brown and Heron in 1879 of a precipitate of starch cellulose from a starch paste digesting with malt extract in the cold. Brown and Heron reported two forms of starch cellulose, one more difficult of solution than the other.^c

Maquenne and Roux^d conclude from their work that amylose exists in a series of convertible forms that may be regarded as different condensation forms of the same fundamental nucleus. Amylocellulose stands at one end of the series and granulose at the other. Cold and concentration of solution tends to change the starch to the amylocellulose form, and heat and dilution to the granular form, but the change to the amylocellulose form takes place only when the granulose has first been dissolved. In addition to the different forms of amylose there is, they believe, another substance present in natural starch grains which they call amylopectin. It is the colloidal substance which causes starch pastes to gelatinize. It does not stain with iodine and it is closely united with the amylose, and while in this combination prevents reversion. The two are separated by solution, whereupon the amylose reverts, and the reverted form containing no amylopectin does not gelatinize after reheating with water. The isolation of amylopectin has not yet been reported. (See p. 16.)

This work on reverted starch suggests some new problems in starch cooking. It would seem that the more thoroughly starch is cooked the more danger there is of its reverting to its most indigestible, i. e., insoluble form, if it is not consumed at once.

It occurred to Roux^e that perhaps reversion took place as bread became stale, but he was unable to find any evidence of the fact, although two years before Lindet,^f working apparently without this theory, had reported finding the starch in stale bread harder to dissolve than that in fresh bread.

These four scientists seem to have overlooked an article by Syniewski^g on the constitution of starch, which appeared in 1899, in which the author concludes that the amylocellulose of Brown and Heron (α -amylose of Meyer) does not exist in the natural starch grain,

^a Compt. Rend. Acad. Sci. [Paris], 137 (1903), pp. 1266-1268.

^b Compt. Rend. Acad. Sci. [Paris], 138 (1904), pp. 819-821; 139 (1904), pp. 1217-1219.

^c Jour. Chem. Soc. [London], 35 (1879), pp. 596-654.

^d Compt. Rend. Acad. Sci. [Paris], 140 (1905), pp. 1303-1308.

^e Compt. Rend. Acad. Sci. [Paris], 138 (1904), pp. 1356-1358.

^f Bul. Soc. Chim. Paris, 3. ser., 27 (1902), pp. 634-639.

^g Liebig's Ann. Chem., 309 (1899), pp. 282-315.

but is formed as a reversion product when for any cause starch goes into solution and is not kept at a high temperature or quickly digested. The reasons he gives for these conclusions are (1) that the methods they employed to isolate this substance were such as would allow of reversion; (2) they obtained varying quantities of it by using different methods, more or less favorable to reversion; (3) they give no satisfactory explanation of the fact that under favorable conditions starch paste is as completely digested as it would be if it contained no indigestible material, and (4) he analyzed the substance prepared as directed for α -amylose and found that it is a hydrated form of starch, instead of starch anhydrid or a condensation product of the same, as suggested by others. Its formula he gives as $(C_6H_{10}O_5)_{9n} + nH_2O$.

Since Syniewski wrote before the theory of amylopectin he naturally said nothing about it, but his theory easily explains without its help the fact that the reverted product does not gelatinize after reheating with water. The starch molecule has decomposed beyond the gelatin-forming stage before it reverts. Syniewski gives in this article and in one ^a that followed it a very interesting theory of the structural formula of the starch molecule and of the various changes that come to it on boiling with water and digestion with enzymes.

Long boiling with water, he says, results in a series of hydration compounds unlike those given by digestion. Because of the place in the molecule where the changes take place, these compounds give the characteristic blue color with iodine, and do not reduce Fehling's solution, as do the products of digestion. These compounds he calls, because of their blue color with iodine, amyloextrins (starch-like dextrins). He has analyzed two of these. The first is the compound formed when by long boiling or by heating in an autoclave the starch first forms a clear solution. He gives to it the formula $(C_6H_{10}O_5)_{9n} + \frac{2}{3}nH_2O$. It is this compound, he says, which easily reverts. Therefore he calls the product "reverted amyloextrin" instead of reverted starch. Its formula is $(C_6H_{10}O_5)_{9n} + nH_2O$. The second of these amyloextrin compounds which he has analyzed he says is the final compound formed by very long boiling with water. He calls it amylogen, and gives its formula as $(C_6H_{10}O_5)_9 + 3H_2O$ or $C_{54}H_{96}O_{48}$. He believes that the starch molecule is an anhydrid condensation product of four amylogen groups, which the long boiling separates into amylogen molecules.

Syniewski agrees with other writers that by digestion with either saliva or malt extract the first stage is a change to a clear solution, i. e., the "soluble starch" of many writers and called by Syniewski "first amyloextrin." After this blue-staining compound, all agree that by continued digestion a mixture results that contains some maltose and a compound staining red with iodine.

^a Liebig's Ann. Chem., 324 (1902), pp. 212-268.

Syniewski calls this maltodextrin I. The hydration, he says, results in breaking one molecule of maltose from each amylogen group in the starch molecule. The next step results in the separation of more maltose, another molecule from each amylogen group, and a compound staining brown with iodine, his maltodextrin II. The term erythrodextrin is often applied to both these red and brown dextrans. The separation of a third molecule of maltose from each amylogen group, he says, results in a compound giving no color with iodine, formed of the residue of these four groups. It is very slow of further digestion. Brown and Heron called it "stable dextrin." Most writers now agree that it is finally converted into maltose and glucose.

If Syniewski is right in believing that there is no substance present in raw starch that is not changed to an easily digestible form by ordinary paste formation, there would seem to be no value in boiling starch a so-called "long time," for the more nearly the paste becomes a solution the more danger is there of reversion, if digestion can not follow at once. Moreover, this change to a soluble form, which it takes hours of boiling to produce, can be accomplished by the first minute of normal digestion which is followed at once by further changes that carry the process beyond danger of reversion.

Being a chemist and not a microscopist, Syniewski was apparently not interested in the physical changes that occur in paste formation—that is, whether outer layers burst or trichites swell. He worked with potato starch and has nothing to say on the relative digestibility of different kinds of starch.

As far back as 1874 D. Levberg^a reported that different quantities of saliva were necessary to produce the maximum quantity of glucose in the same time of digestion. He obtained from potato starch, with 9 cubic centimeters of saliva, 60.3 per cent glucose; from arrowroot starch, with 9 cubic centimeters of saliva, 59.62 per cent glucose; from rice starch, with 10 cubic centimeters of saliva, 55.76 per cent glucose; and from wheat starch, with 16 cubic centimeters of saliva, 62.87 per cent glucose. By varying the experiment he found that it took 8 hours to produce the maximum result from arrowroot starch, 9 hours from potato starch, 12 hours from wheat starch, and 14 hours from rice starch. In both cases it will be noticed that the potato and arrowroot starches showed greater ease of digestion than the rice and wheat starches.

In 1896 Stone^b compared the digestibility of different kinds of starch paste when acted upon by various forms of diastase as shown by the time it took for the digestive mixtures to reach a stage where they could no longer color iodine solution. He found that when treated with malt extract, potato starch required 12 to 15 minutes,

^a Inaug. Diss., St. Petersburg, 1874.
[Bull. 202]

^b Expt. Sta. Record, vol. 8, p. 662.

wheat starch 60 to 90, and maize (corn) starch 90 to 120 minutes. When saliva was used potato starch required 3 minutes, maize starch 90 minutes, rice starch 165 minutes, and wheat starch 170 minutes. With commercial pancreatin, potato starch required 58 minutes, maize starch 337 minutes, while with both rice and wheat starch the digestion was not complete in 10 hours. As an explanation of the differences which were observed in digestibility Stone suggests that starches, like sugar, possibly exist in different isomeric forms.

In 1904 O'Sullivan^a reported that "under similar conditions of hydrolysis with diastase * * * the results obtained from potato starch show no quantitative relationship with those obtained from the other starches." He did not say what these other starches were, but he probably did not use arrowroot starch.

U. Butyazin,^b in 1887, reported that of rice, peas, millet, and buckwheat under the same conditions of cooking and digestion, millet was the most easily digested, then buckwheat, rice, and peas. This author also concluded from his investigations that cooked starch was more digestible than raw starch, and that the digestibility increased with the length of time of cooking.

In this connection some Japanese work reported by S. Kano and S. Iishima^c is of interest. These investigators were themselves the subjects of tests undertaken to study the digestibility of katakuri starch made from *Erythronium dens-canis* and kazu starch made from *Pueraria thunbergiana*. Apparently the starch was cooked and was the sole article of diet. The coefficient of digestibility of the katakuri starch was 95.7 per cent and of the kazu starch 96.6 per cent, values which agree very closely.

The digestibility of konnyaku, a food product prepared from the tuber of *Hydrosme rivieri* (*Conophallus konjak*), which contains mannan as its principal carbohydrate instead of starch, was also studied, the coefficient of digestibility of the carbohydrates being 82 per cent, or considerably lower than the starches.

Judging from the work of O'Sullivan and others there is a difference in the digestibility of different starches, but there would seem to be more difference between potato and "other starches" than between corn and wheat starches.

From the confusion and contradictions a few points stand out. Thus, all authorities agree that starch paste is very much more easily digested than raw starch.

Investigators give no explanation of the cook's insistence on the boiling temperature in cooking starch. In fact, in preparing their pastes for experiments they put no special emphasis on reaching the

^a Jour. Chem. Soc. [London], 85 (1904), p. 616.

^b Inaug. Diss., St. Petersburg, 1887.

^c Bul. Col. Agr., Tokyo Imp. Univ., 2 (1894), No. 2—U. S. Dept. Agr., Office of Experiment Stations Bul. 159.

boiling point or on the length of time that the pastes are cooked. The length of time that a paste stands after it is made, or the temperature at which it stands, or the presence of traces of impurities in the starch are all emphasized as affecting the digestibility, but no one seems to have compared the digestibility of starch cooked below boiling temperature with that actually boiled. Some investigators bring their starch to a boil, others cook a few moments on the water bath after boiling, and others cook on the water bath apparently without any boiling. Their only effort in this direction seems to be to secure a homogeneous paste.

Investigators as well as cooks use care to avoid lumps in cooking starch.

Many investigators use the autoclave with a temperature of 130° to 140° C. in preparing material for experiments; for since the publication of Meyer's results all agree that the entire starch grain goes into solution at that temperature.

The expression "long boiling," as used by investigators, is less definite than the cook's "pinch of salt," but they all agree that it has the same effect as heating to 130° to 140° C. in changing the opalescent paste to a clear solution.

But since those who have experimented with reverted starch agree that starch solutions tend to revert to forms most difficult of digestion, long cooking would seem to be of questionable value.

There is a general agreement among investigators as to the properties of the substance that forms at least the chief mass of starch grains, but there is much disagreement as to the presence in the starch grain of one or more other substances (such as farinose, starch cellulose, α -amylose, amyloextrin, and amylopectin), and of the respective properties of each.

There is an evident discrepancy between the beliefs of practical cooks and the various theories of different scientific investigators. In order to find, if possible, an explanation for this fact and to secure more definite knowledge as to the effects of cooking on the digestibility of starch, the experiments reported in the following pages were undertaken.

Since the investigations reported in this bulletin were completed and the report was prepared for publication several articles by other investigators have appeared which have a bearing on the conclusions drawn. The following papers seem especially interesting in this connection.

Mme. Gratin-Gruzewska^a claims to have isolated the amylopectin of Maquenne and Roux (see p. 12) from potato starch by the use of alkali. She finds by the microscope that the substance is composed of the outer layers of the starch grains. It stains red with iodine.

^a Compt. Rend. Acad. Sci. [Paris], 146 (1908), pp. 540-542.

In warm water it forms a gelatinous paste while the solution from which it is separated does not gelatinize. This so-called amylopectin is the same as the red amylose of this paper. That the blue amylose from which it is separated does not gelatinize is, perhaps, due to the fact that the alkali has hydrolyzed it beyond the gelatinizing stage.

England^a separates thin, well-boiled pastes of corn and barley starches into three layers by using a centrifugal machine and then allowing them to stand for twelve hours. The first or upper layer, he finds, consists of a clear solution that gives the characteristic blue color with iodine and does not gelatinize on standing. He calls it soluble starch. The second layer consists of a white precipitate which stains a reddish color with a little iodine, a purple with more, and a deep blue if still more iodine is added. But if this precipitate is thoroughly washed with water to free it of soluble starch it gives the reddish color alone. On boiling with water it forms a gelatinous paste. He calls it insoluble starch. The lowest layer, when well washed, is pearly white in appearance and gives no color with iodine. He considers that it consists of the broken envelopes of starch grains and calls it cellulose. His insoluble starch probably consists of both rose and red amylose and his cellulose of reverted amylopectin.

Of more practical interest is the work of Harcourt,^b who has recently tried some natural digestion experiments on the effect of cooking rolled oats and wheat farina. He reports that 98 per cent of the carbohydrate of the rolled oats was digested if cooked 20 minutes, while only 0.3 per cent more (98.3 per cent) was digested if the oats were cooked 8 hours. With the wheat farina 98.3 per cent of the carbohydrate was digested if the wheat was cooked 20 minutes, only 0.2 per cent more (98.2 per cent) if first cooked 8 hours. Thus, with natural as well as artificial digestion and with starch combined with the other constituents of the cereal as well as with isolated cereal starch, there is found to be a slight, but only a slight, increase in digestibility secured by cooking for a long time.

MATERIALS, APPARATUS, AND METHODS USED IN EXPERIMENTAL WORK.

The investigations here reported were carried on at the University of Michigan and later at the University of Illinois and at the University of Chicago 1903 to 1906.

The materials used in these experiments were potato, wheat, corn, arrowroot, and several other forms of starch, saliva, malt diastase, and taka diastase.

^a The Cereal Modification of Cow's Milk. [Philadelphia], (1907).

^b Ann. Rpt. Ontario Agr. Col. and Expt. Farm, 32 (1906), p. 63.

In the case of potato starch a commercial sample and several samples prepared in the laboratory were used. The commercial preparation was neutral in its reaction and quite free from solid impurities, and therefore no attempt was made to purify it. For the laboratory preparations new and old potatoes were bought the first of May. The old ones were in very good condition for the time of the year. The new ones were of good size. Both kinds were washed, pared, grated under water, and the grated material filtered through two thicknesses of cheese cloth. The filtering removed the cellulose. To rid the starch of the soluble impurities, it was washed many times by decantation, first in tap water and then in distilled water. It was dried on unglazed porcelain plates below 60° C. Some of the old potatoes were saved and kept in the laboratory locker until the first week in July, when they were found to be much sprouted and shriveled. After removing the sprouts, starch was prepared from these potatoes by the same method.

In the case of the cornstarch, and wheat starch also, commercial samples and laboratory preparations were used. It was found that there were differences in the digestibility of the commercial preparations of cornstarch. Of the three samples tested and designated "A," "B," and "C," respectively, "A" and "B" were put up for culinary use by different firms and both contained solid impurities, largely cellular material. "A" was so alkaline that it required 0.86

cubic centimeters $\frac{n}{100}$ HCl solution to neutralize 1 gram of it, using phenolphthalein as an indicator. "B" was very slightly acid in its reaction. Both were washed with tap water until neutral, and then with distilled water a number of times and dried on unglazed porcelain plates. "C" was bought from a chemical supply house (under the name of wheat starch, though it was really cornstarch) and seemed pure enough to use as it was.

Cornstarch was prepared in the laboratory by washing it from corn meal by the method used with the grated potatoes. The product was not pure. But it seemed much more important to have the starch as nearly as possible in its natural condition, although mixed with impurities, than to use any methods to get rid of these that might change the composition of the starch.

Some difficulty was experienced in obtaining a commercial preparation of wheat starch. Twice cornstarch was received from dealers in response to orders for wheat starch. The sample which was finally obtained was used in the condition in which it was received. An impure starch was prepared in the laboratory from wheat flour by the method used for cornstarch. In this case, too, the desire to keep the starch as nearly as possible in its natural condition prevented further effort at purification.

A commercial preparation of arrowroot starch was bought at a drug store in a tin-foil package. It seemed to be very pure and was used as purchased.

The other forms of starch used were pearled barley, ordinary rice grains, tapioca in three forms, and sago of two sorts. These were bought at a grocery store and used in qualitative experiments without any attempt at purification.

As previously stated, the ferments used in the experimental work were malt diastase, taka diastase, and ptyalin of saliva. In the case of malt diastase, a sufficient quantity of a standard preparation from barley malt was purchased at the beginning for use in all the experiments here reported. A homogeneous mixture was made, which was kept closely corked in a dark-colored bottle. The taka diastase used was also the usual commercial preparation. The saliva was collected fresh for each set of experiments in which it was used.

The apparatus used included a microscope and burettes, pipettes, flasks, etc., such as are needed for ordinary volumetric work.

The hot-water stage for the microscope, mentioned on page 26, was made from a flat bottle of clear glass, which was fitted with a cork with two holes. Through one passed a bent glass tube, the other end of which dipped in a hot-water bath, and through this tube hot water was siphoned into the bottle. A glass tube through the other hole in the cork allowed for the exit of water.

The water bath used for keeping the digestion mixtures at a constant temperature was made double. The outside was a large galvanized-iron can, such as is used for garbage, holding 55 liters of water. Inside of this was a large deep can 10 inches less in diameter holding about 13 liters. This was supported by means of ten wires passing from the rim of the inner can to that of the outer, as the spokes of a wheel from a hollow hub to the rim. Thermometers were kept in both the inner and outer parts. A small gas flame below supplied the heat. An attempt was made at first to regulate the temperature by means of a mercury thermostat, but this proved unsatisfactory. It was found simpler and better to have the burner connected directly with the gas fixture, with a long slender rod attached to the stopcock. In turning the gas up or down the end of this rod described an arc of a large circle. The point on this arc at which the rod rested, when under ordinary conditions the temperature of the inside of the bath was 55° C., was marked on the table. With this normal position determined the gas could safely be turned up or down as needed, and the right temperature being obtained it was found easily possible to keep it constant within one-quarter of a degree for the important first half hour of digestion. In long experiments the temperature often varied two or three degrees during the time when the changes could be noted.

Generally speaking, the different sorts of starch tested were made into a paste with distilled water before treatment with diastase. In making the paste the starch was dried overnight on weighed watch crystals in a calcium chlorid desiccator, with approximately 1 gram of starch on each watch crystal. This quantity was then quickly adjusted to the exact weight of 1 gram, on a delicate balance, and then carefully transferred to an Ehrlenmeyer flask of 170 cubic centimeters capacity and shaken with 5 cubic centimeters of cold distilled water. To this was quickly added in three parts 45 cubic centimeters of boiling distilled water, the mixture being shaken after each addition. The preparation of all pastes for quantitative work was begun in this way, since it involves no risk of losing any of the starch, as does the method ordinarily described of pouring the mixture of starch and cold water into the boiling water. The further preparation of the pastes used in the work reported on pages 25-30 consisted in cooling them to 55° C., the temperature at which they were digested. Other pastes were either boiled or cooked in the boiling water bath the indicated length of time, a return condenser being used in all cases to keep the concentration constant and to prevent skin formation. To prevent lumping, the pastes to be boiled were brought to the boiling temperature with constant shakings before attachment to the condenser. After cooking the given length of time, the pastes were corked and cooled to 55° C., and by means of wires around the necks of the flasks supported inside of the inner part of the constant temperature water bath.

For digesting the starch, malt extracts were made fresh every day. Three and a half grams of the commercial malt powder was mixed with 175 cubic centimeters of distilled water at 55° C. and kept at that temperature for an hour, being shaken every 15 minutes. The solution was then filtered with the aid of an aspirator and heated again to 55° C. Twenty-five cubic centimeters of this extract measured with a pipette was added to 50 cubic centimeters of the starch paste in each flask.

Taka diastase extract, which was used for purposes of comparison, was prepared in the same way as the malt extract, except that the powder was used in the proportion of 4, instead of 5, grams to 100 cubic centimeters of water. It is well known that many species of fungi produce enzymes capable of inverting sucrose and in some cases of converting starch or cellulose into sugar. Taka diastase is a diastase of this sort developed by the fungus *Eurotium oryzae*.^a In a few of the experiments saliva was used.

Two methods were used to determine the extent of the action of diastase, namely, a colorimetric method in which iodine was used as

^a Ztschr. Spiritusindus., 18 (1895), p. 223.

a reagent and a direct determination of the sugar formed with Fehling's solution as a reagent.

The iodine test indicated not only the rapidity of the changes taking place, but something of the products present in the digestion mixture at any given time. For this test glass tubes were kept in the flasks during digestion for the removal of samples. At stated intervals a small quantity was transferred to test tubes and dilute iodine solution added. This stopped digestion, and the tubes being set aside in order, were later carefully compared and notes taken, more iodine being added as needed for color determination. It was found to be unimportant whether or not a definite amount of the digestion mixture and the iodine were combined, for varying amounts of reducing by-products decolorized the solutions, and the tubes standing different lengths of time showed different colors of varying intensity. Moreover, it was found that if at the conclusion of the experiment weak iodine solution was added slowly in excess all color changes could be easily recognized, and the presence of any brownish hue due to dextrin could be distinguished from the yellow of the iodine solution by finally comparing the color in the tube with that of the same sized tube containing an equal amount of the iodine solution with water instead of digestion mixture. This method was found very satisfactory. It could not, however, tell all the story, and needed to be supplemented by the sugar test.

The sugar test is not of so much value in recognizing the delayed digestion of small parts of the starch as is the iodine test, but it supplements it by giving more definite means of comparing the digestibility of the mass of the starch.

With this method the flasks containing the starch and diastase were kept stoppered and shaken every 10 minutes. Digestion was allowed to continue 30 minutes. Then the flasks were removed from the water bath, heated until the contents boiled to stop enzyme action, filtered, the wash waters being added to the solution, and the whole made up to the mark in a 250 cubic centimeter flask. The solution was then tested for sugar by the following modification of a method of Lintner's:

Into test tubes of 40 cubic centimeters capacity was run from burettes 1 cubic centimeter of each of the two parts of Fehling's solution, varying amounts of the digestion mixture, and enough distilled water to make the whole up to 15 cubic centimeters. The tubes were then put in order into a wire holder and together plunged into a boiling water bath, and again removed together at the end of twenty minutes' boiling. The amount of the given sugar solution needed to reduce the 2 cubic centimeters of Fehling's solution was then ascertained by comparison of the tubes. This stage could be determined only approximately at first. After three or four hours'

standing, the red precipitate settled and the last of the blue color of the copper sulphate could be recognized. The end point under these conditions corresponded to 0.01 gram of maltose for every 2 cubic centimeters of Fehling's solution. From the calculated result was subtracted the 0.287 gram of sugar found in 25 cubic centimeters of the malt extract used. This method was found to be much the most satisfactory of the methods tested involving the use of Fehling's solution.

EXPERIMENTS ON THE EFFECT OF COOKING STARCH.

EXPERIMENTS WITH RAW STARCH.

Some preliminary experiments were made with raw starch in which the microscopic appearance and its reaction with iodine were studied and digestion experiments were made.

As is well known, raw starch grains from different kinds of plants vary in their microscopic appearance. The potato and arrowroot

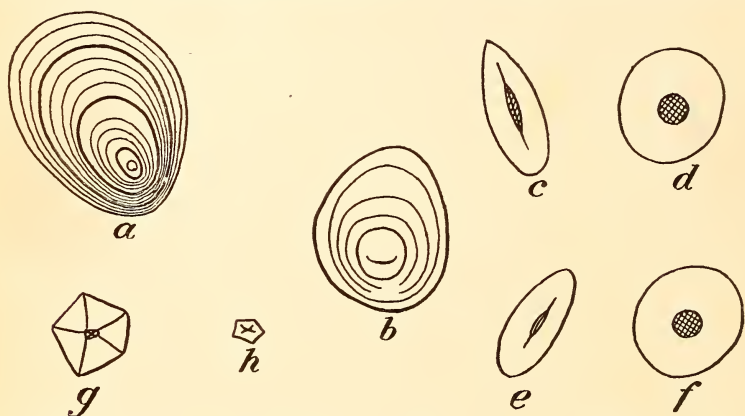


FIG. 3.—Raw starch grains magnified 385 times: *a*, from potato; *b*, from arrowroot; *c* and *d*, from wheat—*c* side view, *d* flat view; *e* and *f*, from barley; *g*, from corn (maize); *h*, from rice.

starch grains are usually irregularly ovoid solid grains, showing no cracks (see fig. 3). The wheat and barley starch grains are lens shaped, generally showing a hollowed space in the center also lens shaped. Rice and corn starch grains are generally polyhedral in shape, with a more or less star-shaped crack in the center of each. As preliminary to the experimental work the different starches were examined with a microscope and compared with standard samples as a means of establishing their identity.

Raw starches of different origin show differences when treated with a solution of iodine. When iodine solution is added to raw starch grains a dark purplish blue results. The potato and arrowroot grains showed but little of the purple, while the other starches which were used showed on standing a decidedly red-purple color.

DIGESTION EXPERIMENT NO. 1.

In this experiment potato, arrowroot, corn, wheat, barley, and rice starches were used. One-half gram of each kind of starch was placed in a flask and to each was added 25 cubic centimeters of cold distilled water, 3 cubic centimeters of fresh unfiltered saliva, and a few drops of thymol solution. The flasks were stoppered and put in the constant temperature water bath at 40° C. The samples were tested with the naked eye and with the microscope at the end of 14 and 38 hour periods.

With the naked eye no appreciable diminution in the quantity of solid starch in the bottom of the flask was noticeable at either time.

At the end of 14 hours neither the potato nor arrowroot grains showed any change when examined with a microscope except a slight swelling. In most of the corn and rice starch grains the center was apparently all dissolved, leaving behind a thick shell which showed long deep clefts along what were the edges of the solid polyhedral grain (see fig. 4, *a*). In the case of wheat and barley starches many of the grains showed no change except corrosion at the surface, but many others were nothing but hollow shells, thinner than in the corn, with pitted surfaces and cracks around the edge much like the openings of oyster shells (see fig. 4, *b*). At the end of 38 hours many arrowroot grains showed surface corruptions (see fig. 4, *c*). Some potato starch grains showed the same kind of corruptions. Others showed a change at the small end (see fig. 4, *d*). While the rest of the starch grain stained a deep blue with iodine, the small end did not stain at all, but appeared to be of a colorless glistening substance less solid than the rest of the grain and showed the same laminated appearance. The corn, rice, wheat, and barley starch grains appeared practically the same as the day before. They slowly stained a blue red with iodine. At some places at the surface the same glistening colorless substance noted in the potato grains was apparent.



FIG. 4.—Raw starch grains that have been digested 38 hours: *a*, corn-starch showing clefts at what were the edges of the grain; *b*, wheat starch grain, side view, showing oyster-shell-like opening and pittings; *c*, arrowroot starch grain showing corruptions; *d*, potato starch grain stained with iodine, showing colorless reverted amylopectin and no starch at the small end.

DIGESTION EXPERIMENT NO. 2.

The conditions were the same as in experiment No. 1, except that malt extract was substituted for saliva and the mixture was digested at 55° C. instead of at 40° C. The results obtained were practically the same as with saliva.

DIGESTION EXPERIMENT NO. 3.

In this experiment potato and corn starches were used, each sample being treated with 25 cubic centimeters of malt extract and 50 cubic centimeters of distilled water added to 1 gram of raw starch. The samples were digested at 55° C. for 24 hours and were tested with Fehling's solution according to the method outlined on page 21.

At the end of 24 hours the tests showed that about 10 per cent of the potato starch and about 27 per cent of the cornstarch were changed to maltose.

From these tests with raw starch it seems fair to conclude that raw starch digests slowly, and that starch grains that are cracked digest more rapidly than those that are solid.

There seems to be evidence furnished by the experiments in support of the theory that the outer layer of starch grains is more difficult of digestion than the inner layers. In the flattened starch grains of corn, rice, wheat, and barley the outer layer seems to be weakened at the edges, so that while the rest of the surface is being corroded slowly more rapid solution takes place at the edges and along the cracks on the inside. In the rounded, uncracked grains of potato and arrowroot starches there are no easy points of attack. The inside is too dense for rapid enough diffusion inward of the diastase and outward of the digestion products, and the outer layer is practically homogeneous except that it is thinner at the small end in the potato starch grain because the hilum or point of origin is at this end. Hence it is that in this grain the outer layer dissolves first at the small end.

The colorless substance remaining at the end of the digestion period may be reverted amylopectin, since digestion is very slow.

Judging by the results of the digestion tests, and from their normal condition and appearance without treatment, the six kinds of starch studied naturally group themselves into two divisions, namely: Wheat, corn, barley, and rice starches and potato and arrowroot starches.

In the case of the wheat, corn, barley, and rice starches the natural spherical form has become flattened. The starch grains show internal cracks and a red-purple stain with iodine on standing. The digestion is apparently more rapid than with the second group.

In the case of the potato and arrowroot starches a rounded form is retained; normally no internal cracks are visible, and a blue-purple

stain is obtained with iodine which does not become red purple on standing. The digestion is very slow.

The starch grains of the first group are produced in the crowded cells of seeds and hence their flattened form. In these cells the loss of water on maturing is great and hence the cracks.

The starch grains in the second group are produced in less crowded cells, and are not flattened. The drying at maturity is much less and so there are fewer cracks.

EXPERIMENTS WITH STARCH COOKED BELOW THE BOILING TEMPERATURE.

That starch may be cooked it is essential that every starch grain be brought into contact with water of at least 60° to 80° C. (140° to 178° F.). If it is to be cooked below boiling temperature, this is best accomplished for quantitative work by simply adding boiling water to a mixture of starch and cold water and shaking. But a paste can

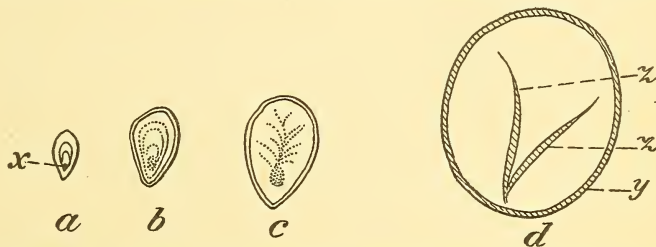


FIG. 5.—Potato starch magnified 87 times, showing successive stages in paste formation: Changes that come with the absorption of hot water—*a*, raw starch; *x*, hilum or point of origin; *b* and *c*, intermediate stages, showing granulation beginning at the point of origin; *d*, condition in unboiled paste; *y*, outer layer; *z*, folds in outer layer.

be made equally well by the more common method of pouring the mixture of starch and cold water into boiling water while stirring.

The same starches were used as in the previous tests. When the pastes were examined with the naked eye, marked differences were noted between potato and arrowroot starch on the one hand and corn and wheat starch on the other. The potato and arrowroot pastes were colorless and transparent, while the others were whitish, more opaque, and appeared to be less thoroughly cooked. In all cases the pastes made without boiling separate on standing a short time, the starch sinking to the bottom.

When examined with the microscope it was apparent that the starch grains were much swollen but were not broken. The transition from the raw to the swollen condition can be observed with the microscope if the paste is made by using all cold water and gradually raising the temperature. The absorption of water by the starch grain begins at the point of origin. It shows as a granulation which gradually works its way outward (see fig. 5) until nothing solid but the

outer layer is left in the potato and arrowroot starch grains. In the corn and wheat some of the granular material also remains in solid form (see fig. 6). It is probably this which causes the opacity in

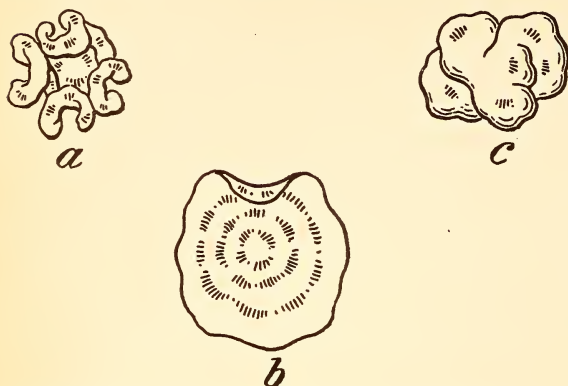


FIG. 6.—Starch grains from unboiled pastes: *a* and *b*, wheat starch—*a*, collapsed swollen grain with edges curved over and solid granular material; *b*, the same grain flattened out by heating on the hot-water stage; *c*, collapsed swollen grain of cornstarch showing solid granular material.

these pastes. The outer layer is greatly stretched and, if the paste is cooled, collapses. Sometimes these collapsed forms are hard to recognize as such. In the wheat this is especially true. The edges of the flattened form curve over on themselves so that the result often looks more like a star than a ball (see fig. 6, *a*), but by using a hot-water stage (see p. 19) on the microscope these forms can be seen to unroll gradually (see fig. 6, *b*) and to stretch out to their original swollen form.

Details of the artificial digestion experiments follow which were made with the starch pastes cooked below boiling temperature.

DIGESTION EXPERIMENT NO. 4.

In this test potato, arrowroot, corn, and wheat starches were used, each sort being made into a paste by adding boiling water to a mixture of starch and cold water and shaking. Undigested samples and samples digested for different lengths of time with malt diastase were treated with small, medium, and large amounts of iodine and the color reactions noted as a means of judging of differences attributable to the several sorts of starch and the length of the digestion period. The potato and arrowroot starches and the corn and wheat starches are grouped together, because in each case these starches gave the same color reactions.

TABLE 1.—*Digestibility as indicated by iodine test of different starches cooked below 100° C.*

Time of digestion of starch.	Amount of iodine used.	Color produced with iodine in—	
		Potato and arrowroot starch.	Corn and wheat starch.
No digestion.....	Little.....	Pure blue.....	Old rose.
Do.....	Medium.....	do.....	Pure blue.
Do.....	Excess.....	Green <i>a</i>	Green.
2 minutes.....	Little.....	Pure blue.....	Old rose.
Do.....	Medium.....	do.....	Pure blue.
Do.....	Much.....	Purple.....	Purple.

a Green color is due to the blue of the reaction with the yellow of the iodine.

TABLE 1.—*Digestibility as indicated by iodine test of different starches cooked below 100° C.—Continued.*

Time of digestion of starch.	Amount of iodine used.	Color produced with iodine in—	
		Potato and arrowroot starch.	Corn and wheat starch.
3 minutes.....	Little.....	Pure blue.....	Old rose.
Do.....	Medium.....	Purple.....	Pure blue.
Do.....	More.....	do.....	Purple.
Do.....	Much.....	Red.....	Red.
4 minutes.....	Little.....	Pure blue.....	Old rose.
Do.....	Medium.....	Purple.....	Pure blue.
Do.....	More.....	do.....	Purple.
Do.....	Still more.....	Red.....	Red.
Do.....	Much.....	Brown.....	Brown.
6 minutes.....	Little.....	Purple.....	Old rose.
Do.....	Medium.....	Red.....	Pure blue.
Do.....	More.....	do.....	Purple.
Do.....	Still more.....	do.....	Red.
Do.....	Much.....	Brown.....	Brown.
8 minutes.....	Little.....	Red.....	Old rose.
Do.....	Medium.....	Brown.....	Blue.
Do.....	More.....	do.....	Red.
Do.....	Much.....	do.....	Brown.
10 minutes.....	Little.....	do.....	Old rose.
Do.....	Medium.....	do.....	Blue.
Do.....	Much.....	do.....	Blue brown.
20 minutes.....	Little.....	Yellow (iodine color).....	Old rose.
Do.....	Medium.....	do.....	Blue.
6 days.....	Very little.....		Old rose.
Do.....	Little.....		Brown.
Do.....	Medium.....		Yellow (of iodine).
7 days.....	Any amount.....		Do.

The periods of time in the first column represent the number of minutes required to produce the color stages indicated in the third and fourth columns. That is, the red color shows at the end of 3 minutes, the brown at the end of 4 minutes; the red disappears at the end of 10 minutes, and the brown at the end of 20 minutes. It takes 6 days for the blue connected with the old rose color to disappear.

The change of color that comes from the varying amounts of iodine used is no doubt due to the presence in the digestion mixture of various compounds which stain differently with iodine and which have for it various degrees of affinity. The colors given in column 3 for digesting potato and arrowroot starches may be explained as follows: The blue indicates either starch or Syniewski's amylopectin, and the brown and red are two other dextrans, called here for the sake of simplicity according to the color they take with iodine, red dextrin and brown dextrin. The starch and amylopectin have the greatest affinity for the iodine, and only after more than enough iodine has been added to stain blue all the starch and amylopectin present can any permanent red or purple be obtained. After this, if there is enough red dextrin present to dominate the blue, we see this color; otherwise we have the purple mixture. All the red and blue dextrin having united with iodine, the brown dextrin begins to show, and if it is present in large enough quantities the brown hue alone appears. As digestion proceeds, first the blue, then the red, and then the brown dextrin diminishes in volume and disappears. With the corn and wheat starches there is the same series of color

changes, but in addition there is another series which, especially with this method of cooking, often conceals the one corresponding to that of the potato and arrowroot starches. In order to get the gradation of color noted in columns 3 and 4 care must be taken to add enough iodine and to do it slowly. The "old rose" differs not at all in color from some mixtures of blue and red dextrin with iodine, and heretofore has evidently been taken for the same, but as shown here the compound stained old rose has a stronger affinity for iodine than the blue dextrin, while red dextrin has a less affinity. The old rose always appears before the blue with these starches if iodine is added slowly. Moreover, this red is not quickly changed to brown by digestion, as is the red dextrin, but continues for days rather than for minutes.

However, it must not be concluded, because it takes corn and wheat starches over 500 times as long as potato and arrowroot starches to reach the point in digestion where they no longer color iodine solution, that the relative digestibility of the two pairs can be expressed by the ratio 1:500; for the part of the paste which is slow to digest represents only a small percentage of the whole, as is indicated by the slight color in the test tubes after 20 minutes' digestion. Moreover, there are probably factors, such as the accumulation of by-products, which make the digestive process increasingly difficult as time progresses.

When examined with the microscope it is seen that the swollen starch grains before digestion give to the paste the blue color with iodine, but after a minute's digestion this color is seen also in the solution outside of the grains without any apparent break in the outer layer. When most of the blue substance has diffused out, this outer layer is seen to be stained red. It persists until the red dextrin is the dominant compound in solution, and then quite quickly disappears. After the solution of the outer layer the digesting potato and arrowroot mixtures are free from solid substance. The fine granular substance of the corn and wheat starches, however, continues undissolved. The particles are so tiny that they pass through a filter paper. They stain old rose with iodine and undoubtedly explain the long continuance of that color in the test-tube examinations.

DIGESTION EXPERIMENT NO. 5.

In this experiment arrowroot, potato, wheat, and corn starches were used, unboiled paste being prepared from each as in digestion experiment No. 4. When the pastes, after digestion with malt diastase, were tested with Fehling's solution the arrowroot showed 71 to 73.5 per cent maltose, potato 72 to 74 per cent, wheat 63.8 to 66 per cent, and corn 58 to 60 per cent.

A comparison of these figures with those given as the result of digestion experiment No. 2 shows that under the same digestive

conditions, but in one forty-eighth of the time, unboiled pastes of potato starch yield about seven times as much maltose as does the raw potato starch, while cornstarch paste yields only about twice as much as the raw cornstarch. However, it does not necessarily follow that potato-starch paste is 336 times as digestible as raw potato starch, or that cornstarch paste is 96 times easier of digestion than raw cornstarch.

From the work on starch cooked below boiling temperature it seems fair to conclude that starch pastes need not be boiled to make them much easier of digestion than raw starch. These experiments show yet another difference between potato and arrowroot starches on the one hand and corn and wheat starches on the other (see pp. 24, 25). There is present in corn and wheat starches a substance not found under these conditions in potato and arrowroot starches. It has the following properties: It stains old rose color with iodine, it has more affinity for iodine than starch or blue dextrin, it is soluble in warm water, and it digests very slowly.

It would seem, therefore, that it can not be the amylopectin, which Meyer thinks is present in those grains that stain red with iodine, for that is soluble in warm water and easily digestible. Nor can it be Syniewski's maltodextrin I (the erythropectin of others) which stains red with iodine, but is very easily soluble in warm water and very easily digestible, and which has less affinity for iodine than blue dextrin. It is evidently not a reversion product, for its color shows in the raw starch grains. It has some of the properties of Meyer's α -amylose, in that it stains red with iodine, and is difficult of solution and digestion. However, this substance is not distributed in the starch grains as he believed α -amylose to be distributed. For the sake of simplicity this starch constituent may be called rose amylose.

There is present in all the swollen starch grains tested a substance with the following properties: It stains blue with iodine, it digests rapidly even if the outer layer has not been broken, and it apparently constitutes the whole of the potato and arrowroot starch grains except the outer layer and all of the inside of the corn and wheat starch grains except about 10 per cent which is rose amylose. It is evidently the β -amylose of Meyer, the granulose of others. For the sake of uniformity this portion or constituent of the starch grain may be called blue amylose.

It was further evident from the digestion experiments reported that the outer layer of the starch grain is not broken or dissolved in paste formation below 100° C. It stains red with iodine and is perhaps the cause of the slight purple hue seen in raw potato and arrowroot starches so stained; it is harder of digestion than blue amylose; it is easier of digestion than rose amylose, and it seems to

differ from the other layers in more respects than in density, since even in its stretched condition it stains red instead of blue or rose with iodine. Perhaps it is formed as a result of changed conditions in the cell sap that come after the end of the growth period in the plant, and which might affect the outer layer most because of its position even though the whole grain be porous. The substance of this layer may be called red amylose.

EXPERIMENTS WITH STARCH BOILED 5 MINUTES.

The pastes which are made by boiling the starch for 5 minutes are more homogeneous and do not show the tendency to separate which is noted with unboiled pastes. The cereal starch pastes are still not clear when thus cooked though the others are.

The microscope shows that large numbers of the starch grains have broken, corn and wheat starches showing a multitude of fragments of broken outer layers and more or less granulated inner parts. With the arrowroot and potato starches the outer layers are more persistent and, collapsed as they are, it is often hard to see the breaks, but with iodine it is easy to see by their greater transparency that they have lost their inner parts, which are more uniformly soluble than in the other starches.

DIGESTION EXPERIMENTS NOS. 6 AND 7.

In these experiments both methods and conditions were the same as in digestion experiments Nos. 4 and 5 except that the pastes were boiled 5 minutes, and the results obtained were on an average the same as those given on pages 26-30 for the experiments with the unboiled pastes, all of which are included in Tables 2, 3, and 4 for purposes of comparison.

The conclusion may therefore be drawn that brief boiling, while it breaks many starch grains and makes a better paste, does not appreciably improve the digestibility of the starch.

EXPERIMENTS WITH STARCH BOILED MORE THAN 5 MINUTES.

To prevent the formation of skin and the loss of water all the samples were boiled in a flask with a return condenser.

With continued boiling the pastes gradually change in appearance and character. At the end of 3 hours they are distinctly more homogeneous, less viscous, and more transparent, and they also acquire a slight yellowish tinge. The taste is changed from one more or less suggestive of the odor of boiling laundry starch to one very slightly suggestive of caramel. This slight change of color and taste is not due to any ordinary scorching, because there is no apparent sticking of the paste to the bottom or sides of the flask. The microscope shows a gradual diminution in the solid material, i. e., the outer layers and granular substance present.

DIGESTION EXPERIMENT NO. 8.

Potato and arrowroot starches were used for this experiment, and the pastes were boiled for 3 hours and were treated with malt diastase in the usual way. The results obtained are summarized in the following table, which shows the time required for the brown dextrin reaction to disappear from the digestion mixture. For purposes of comparison the results of similar tests with unboiled starch and with starch pastes boiled for 5 minutes are also included.

TABLE 2.—*Changes brought about in potato and arrowroot starches by long continued cooking.*

Kind of starch.	Time required for disappearance of brown dextrin reaction.			Kind of starch.	Time required for disappearance of brown dextrin reaction.		
	With unboiled pastes.	With pastes boiled 5 minutes.	With pastes boiled 3 hours.		With unboiled pastes.	With pastes boiled 5 minutes.	With pastes boiled 3 hours.
Arrowroot.....	<i>Minutes.</i> 19-20½ 18½-21½	<i>Minutes.</i>	<i>Minutes.</i> 18½-20½ 19½-20½	Potato.....	<i>Minutes.</i> 19-21 17-18 20-25 23-25	<i>Minutes.</i> 20-25 19-23	<i>Minutes.</i> 18-20 19-21½ 19-24 20-25
Average.....	20	.....	20	Average.....	21	21½	20½

DIGESTION EXPERIMENT NO. 9.

In this experiment arrowroot starch was used. The paste was boiled for 3 hours, when, after digestion in the usual way and tested with Fehling's solution, it was found that 71 to 73.5 per cent of starch had been converted into maltose—the same quantity which was noted in the case of unboiled arrowroot paste (see p. 28).

It would therefore appear from the results obtained in the digestion experiments Nos. 8 and 9 that potato and arrowroot starches are not made more digestible by boiling.

DIGESTION EXPERIMENT NO. 10.

The cornstarch used was a commercial preparation designated "A." The unboiled pastes and samples, boiled from 5 minutes to 3 hours, were prepared, digested in the usual way, and tested with iodine. The results which were obtained are as follows:

TABLE 3.—*Changes brought about in cornstarch by long continued cooking.*

No. of test.	Time required for disappearance of red dextrin color reaction with paste.					Time required for disappearance of brown dextrin color reaction with paste.				
	Un-boiled.	Boiled 5 min-utes.	Boiled 30 min-utes.	Boiled 45 min-utes.	Boiled 3 hours.	Un-boiled.	Boiled 5 min-utes.	Boiled 30 min-utes.	Boiled 45 min-utes.	Boiled 3 hours.
1.....	<i>Min.</i> 7-16	<i>Min.</i> 9-12	<i>Min.</i> 7-10	<i>Min.</i> 6-9	8.5-9.5	<i>Hrs.</i> 23-24	<i>Hrs.</i> 28-29	<i>Hrs.</i> 2.3-2.5	<i>Hrs.</i>	<i>Min.</i> 51-59
2.....	5-14	8-11	7.5-12	6-13	8-12	24-25	26-27	2.5-3.3	1.2-1.7	.....
3.....	9-12	.....	.....	.....	.....	21-22	.....	.....	.....	.....
4.....	10-18	.....	.....	.....	.....	21-22	.....	.....	.....	.....
Average...	11	10	9.25	11	9.5	23	27	2½	1½	55

Comparison with Table 1 makes the results of this experiment more easily understood. The first part of Table 3 corresponds with the results given in Table 1 with samples cooked 10 minutes and shows the time which it takes for the disappearance of the red dextrin of the easily digested portion. As explained in connection with Table 1, it is impossible to see the transition at the end of 20 minutes with corn and wheat starches.

The relatively rapid digestion of the rose amylose (23 hours instead of over 7 days, as noted in the experiment reported in Table 1) is doubtless due to some peculiarity of the preparation of cornstarch used (see pp. 18, 27).

From the experimental data it would appear that the blue amylose of corn, as of potato and arrowroot starches, is not made more easily digestible by long boiling. The rose amylose of cornstarch is apparently made more quickly digestible by long boiling because some of it is changed to blue amylose.

DIGESTION EXPERIMENT NO. 11.

In this, as in the preceding test, commercial cornstarch designated "A" was used. The pastes were boiled for 5 minutes, 30 minutes, 1 hour, and 3 hours, respectively, and digested for 30 minutes. When tested with Fehling's solution it was found that a sample boiled 5 minutes gave 59 to 61.2 per cent maltose; the paste boiled 30 minutes 60 to 62.1 per cent; the paste boiled 1 hour 63.3 to 65.1 per cent, and the paste boiled 3 hours 62.1 to 65.7 per cent, as compared with 58 to 60 per cent maltose in the case of unboiled pastes. Judged by the data reported there is a distinct increase in the percentage of maltose formed in 30 minutes' digestion of cornstarch pastes, boiled 1 and 3 hours, over those cooked shorter lengths of time.

DIGESTION EXPERIMENT NO. 12.

Samples of pastes made from wheat starch were boiled for 1 and 3 hours, respectively, and digested with malt extract in the proportion commonly used in the experiments, namely, 25 cubic centimeters of malt extract and 50 cubic centimeters of water to 1 gram of starch. When tested with iodine all the samples required over 7 days for the disappearance of the characteristic dextrin color, the only noticeable difference being that with the pastes boiled for the longer period there was less substance left undigested at the end of 20 minutes than with the other pastes.

DIGESTION EXPERIMENT NO. 13.

In this experiment wheat starch was used and the paste was boiled for different periods of time. The proportion of malt extract to starch used for digesting the paste was ten times greater than in the majority

of the tests, 50 cubic centimeters of malt extract and 20 cubic centimeters of water being used to 0.2 gram of starch. The results obtained upon testing with iodine are shown in the following table:

TABLE 4.—*Changes brought about in wheat starch by cooking for different lengths of time.*

Kind of starch.	Time required for disappearance of red dextrin color reaction with paste.				Time required for disappearance of brown dextrin color reaction with paste.			
	Un-boiled.	Boiled 5 minutes.	Boiled 1 hour.	Boiled 3 hours.	Un-boiled.	Boiled 5 minutes.	Boiled 1 hour.	Boiled 3 hours.
Wheat starch:	<i>Minutes.</i>	<i>Minutes.</i>	<i>Minutes.</i>	<i>Minutes.</i>	<i>Hours.</i>	<i>Hours.</i>	<i>Hours.</i>	<i>Hours.</i>
First test.....	3-5	5-7	5-6	3½-5	4-18	4-18	4-18	1-1½
Second test.....	4-5	3½-4½	5-6	4-5	4-18	4-18	4-18	1-2½
Average.....	4½	5	5½	4½	.....	.....	.....	.....

No difference is apparent from the data included for the disappearance of the brown dextrin color reaction, owing to the fact that the end points of the reaction occurred some time during the night, when it was not possible to make the necessary observations. There was, however, as in experiments Nos. 6 and 8, a noticeable difference between the pastes boiled not more than 5 minutes and those boiled 1 and 3 hours, as shown by the quantity of undigested material left at the end of 20 minutes.

It seems fair to conclude, therefore, that increasing the proportion of diastase to starch shortens the time required for both stages of digestion. Long boiling makes the rose amylose of wheat starch more easily digestible, as is the case with cornstarch, and as previously found has no effect on the blue amylose.

DIGESTION EXPERIMENT NO. 14.

In this test wheat starch pastes boiled for different periods of time were used. The pastes were digested with the ordinary proportions of malt extract, namely, 25 cubic centimeters malt extract and 50 cubic centimeters water for 1 gram of starch. On testing with Fehling's solution it was found that the unboiled pastes showed 64.8 to 68.3 per cent maltose in the first test and 63.8 to 66 per cent in the second test. In the case of the samples boiled 3 hours 64.8 to 67.3 per cent maltose was noted in the first test, and 67.5 to 70.5 per cent in the second test.

The increase in digestibility due to long boiling, as indicated by the production of maltose, is small, being even less than was noted with cornstarch. There seems to be a discrepancy between the results of the iodine test (experiment No. 13) and the test with Fehling's solution. The iodine test would indicate that wheat starch is more difficult to digest than cornstarch, while the test with Fehling's solution

would indicate the reverse. Further investigation is required, therefore, before general conclusions can be drawn regarding the relative digestibility of wheat and corn starches.

In general, the conclusion seems warranted, from experiments Nos. 8 to 13, that pastes made from potato and arrowroot starches, which have been boiled even for 3 hours, do not digest more quickly than similar pastes made with hot water but not heated to the boiling point. Corn and wheat starches are rendered somewhat more digestible by long boiling owing to the gradual change of the rose amylose which they contain to blue amylose. A long cooking period is, however, necessary, as the change to blue amylose is not complete after 3 hours' boiling.

EXPERIMENTS WITH STARCH COOKED IN A WATER BATH OR DOUBLE BOILER.

When starch paste is cooked in a water bath or double boiler, in which the water is kept at boiling temperature, the starch grains do not break but settle to the bottom of the vessel in which the paste is cooked.

DIGESTION EXPERIMENT NO. 15.

Cornstarch was used in this experiment and was cooked in a boiling water bath for 1 hour, using a flask with a return condenser. The temperature of the starch mixture itself was found to be 95° C. When the mixture, after digestion in the usual way, was tested with iodine it was found that the brown dextrin disappeared in 5 to 18 hours as compared with 23 hours in the case of unboiled paste and 2½ hours in the case of starch boiled 30 minutes, the values which were obtained in previous tests.

The conclusion is drawn, therefore, that cooking cornstarch below 100° C., as in a water bath, increases its digestibility, but not so rapidly as cooking at 100° C.

EXPERIMENTS ON THE DIGESTIBILITY OF STARCH BY DIFFERENT DIASTASES.

It was felt that it was desirable to compare the digestibility of starch by malt extract with that by other diastases, and so experiments were undertaken in which ptyalin and taka diastase were used.

DIGESTION EXPERIMENT NO. 16.

Wheat, corn, and potato starch pastes were prepared in the usual way and boiled for 1 minute. One sample of wheat starch was also boiled for 3 hours. The samples were digested with saliva (see p. 19) and then tested with iodine. In the case of potato starch

boiled for 1 minute the brown dextrin reaction disappeared in 8 to 12 minutes, and with corn and with wheat starch, cooked the same length of time, in 24 hours in each case, while with wheat starch cooked 3 hours 3 to 18 hours were required. The corn and wheat starches showed the slow disappearance of rose color, but the potato starch did not.

The ptyalin of saliva, like malt extract, according to the data reported, digests potato starch quickly and corn and wheat starch slowly. When wheat starch was boiled for 3 hours it was digested more quickly than when boiled for 1 minute.

DIGESTION EXPERIMENT NO. 17.

Wheat, corn, and potato starch pastes were prepared, using 1 per cent of starch, and were cooked on a water bath for one-half hour. The digestibility was tested with taka diastase, using equal quantities of the diastase solution (see p. 20) and starch. The digestion was carried on at a temperature of 65° C. On testing with iodine it was found that the brown dextrin reaction disappeared in 12 minutes with potato starch and with both the wheat and corn starch pastes in 20 hours. The rose color appeared with the corn and wheat starches, but not with the potato starch.

From the tests reported, therefore, it would appear that diastase of animal origin, ptyalin, and taka diastase, a diastase derived from a fungus (*Eurotium oryzae*), show the same reaction on blue and rose amylose as does the malt diastase obtained from barley.

It was thought possible that the results obtained in the foregoing experiments might be due in part to the particular sample of starch used, so efforts were made to obtain other samples and to use them in check experiments as follows:

EXPERIMENTS ON THE DIGESTIBILITY OF DIFFERENT PREPARATIONS OF THE SAME KIND OF STARCH.

DIGESTION EXPERIMENT NO. 18.

Starch prepared from new potatoes, from old potatoes, and from much-sprouted potatoes, and a commercial potato starch preparation were used in this experiment, none of the pastes being boiled. The color changes found on testing with iodine were the same as those reported for potato starch in Table 1 (p. 26), and there was no indication of rose amylose in any of the preparations. The time required to reach the achromatic point was apparently the same with all the samples. The brown dextrin reaction disappeared with the starch made from new potatoes in 18 to 19 minutes in the first test and in 22 to 23 minutes in the second test; with starch made from

old potatoes in 20 to 25 minutes in the first test and in 20 to 21 minutes in the second; with starch made from much-sprouted potatoes in 16 to 18 minutes in the first test and in 15 to 17 minutes in the second, and with paste made from commercial potato starch in 17 to 18 minutes in the first test, 20 to 25 minutes in the second test, and in 24 to 25 minutes in a third test.

On the basis of the reported data it would seem fair to conclude that rose amylose is not present in potato starch in such quantities as to appreciably affect its digestibility.

DIGESTION EXPERIMENT NO. 19.

Unboiled pastes were made from cornstarch prepared in the laboratory from corn meal, and from three commercial cornstarches designated "A," "B," and "C," respectively. The results, which were obtained on testing with iodine, after digestion in the usual way with malt diastase, are shown in the table which follows:

TABLE 5.—*Comparison of digestibility of unboiled pastes made from cornstarches of different origin.*

Kind of starch.	Time required for disappearance of red dextrin color reaction.	Time required for disappearance of brown dextrin color reaction.	Kind of starch.	Time required for disappearance of red dextrin color reaction.	Time required for disappearance of brown dextrin color reaction.
Starch made from corn meal:	<i>Minutes.</i>	<i>Hours.</i>	Commercial cornstarch "B.":	<i>Minutes.</i>	<i>Hours.</i>
First test.....	6-14	8-23	First test.....	7½-9	168
Second test.....	5-13	8-23	Second test.....	7½-9	-----
Commercial cornstarch "A.":			Commercial cornstarch "C.":		
First test.....	7-16	23-24	First test.....	6-15	168
Second test.....	5-14	24-25	Second test.....	6-9	-----
Third test.....	9-12	21-22			
Fourth test.....	10-18	21-22			

As will be seen from the table, a great difference was noted with the four samples of starch in the time required for the last stage of digestion, i. e., the disappearance of the brown dextrin. No explanation of this difference has been found, and the point is an important one which requires further attention.

From the recorded data it seems fair to conclude that both blue amylose and rose amylose are normal constituents of cornstarch.

DIGESTION EXPERIMENT NO. 20.

Unboiled pastes were prepared from a commercial wheat starch, from a sample of wheat starch prepared in the laboratory, and from wheat starch in the form of wheat flour, and were tested with iodine after digestion in the usual way. In all cases digestion occurred in two stages, the old-rose color appearing.

The conclusion was reached, therefore, that both blue and rose amylose are normal constituents of wheat starch.

In general, it seems fair to conclude that the results obtained in experiments Nos. 4 to 18 on the composition and digestibility of wheat, corn, and potato starches are normal and are not ascribable to the different methods used in isolating the starches.

ADDITIONAL ATTEMPTS TO IDENTIFY ROSE AMYLOSE IN POTATO STARCH.

Since recognizable quantities of rose amylose in wheat and corn starch are found to vary with experimental conditions, it was thought that it might possibly be detected in potato starch under conditions unfavorable for digestion and three experiments were made to study this point.

DIGESTION EXPERIMENT NO. 21.

A sample of unboiled paste was prepared and digested at 61° C. instead of 55° C. On testing with iodine it was found that the time of digestion was slightly increased, but there was no indication of rose amylose.

DIGESTION EXPERIMENT NO. 22.

Unboiled potato starch paste was treated with a fifth as much diastase as was used in the majority of the experiments, the quantities being 5 cubic centimeters of malt extract and 50 cubic centimeters of water to 1 gram of starch. The time required to reach the achromatic point was increased from 20 to 80 minutes, but there was no indication of rose amylose.

DIGESTION EXPERIMENT NO. 23.

Raw potato starch ground with glass fragments to break the outer layers of the starch grain was tested with iodine and it was apparent that digestion occurred much more rapidly than with unbroken raw starch, but much more slowly than with starch grains which had been swollen with hot water. When examined with the microscope they showed that the outer layer was red with iodine whenever it was separated from the inner parts, but the digestion mixture tested with iodine in test tubes showed no old-rose color before the blue and no tendency of the blue to revert to the old-rose color on standing.

The general conclusion seems warranted, therefore, that rose amylose is not present in potato starch. The red amylose of the outer layer of the potato starch grain does not give the same reaction.

THE POSSIBILITY OF REVERSION IN WHEAT AND CORN STARCHES.

According to Maquenne and Roux, reversion does not occur above 60° C. The following experiment was made to determine whether rose amylose is a reversion product:

DIGESTION EXPERIMENT NO. 24.

Unboiled pastes were made from wheat and corn starches and care was taken not to cool the pastes below 61° C., and digestion was continued at this temperature. Treatment with iodine showed that digestion was retarded in both cases, but the results were otherwise the same as in previous experiments.

From the results of this experiment and the fact that the rose color is also apparent in the raw grain on treatment with iodine, the deduction would seem warranted that rose amylose is not a reversion product.

Little work was done on the subject of the formation and properties of the possible reversion product in connection with the investigations reported in this bulletin, but enough was accomplished to suggest that such a reversion product is formed when raw starch digests slowly, when starch pastes are frozen, when a skin forms on starch paste, and when a partially digested starch paste stands at ordinary laboratory temperature. It does not seem to be formed when dilute (2 per cent) starch pastes are kept stoppered for 24 hours at ordinary laboratory temperature.

As regards the properties of this reversion product, it does not stain with iodine; it is more difficult of solution and digestion than rose amylose, and it dissolves in potassium hydroxid, forming a solution which after neutralization gives the characteristic blue color with iodine.

This reversion product, which is probably the same as Syniewski's reverted amyloextrin, may be regarded as distinct from the red amylose and rose-amylose bodies, which are apparently now for the first time definitely identified, but it has undoubtedly been confused with them by earlier investigators who have variously called it starch cellulose, amylocellulose, farinose, and α -amylose. Further investigations are necessary before definite conclusions can be drawn as to the dietetic significance of the reversion of starch.

EXPERIMENTS ON THE DIGESTIBILITY OF TAPIOCA, SAGO, PEARLED BARLEY, AND RICE STARCH.

In connection with the investigations which have been reported it seemed desirable to test the digestibility of some other common sorts of food starches and accordingly tapioca, sago, pearled barley, and rice were selected for study.

DIGESTION EXPERIMENT NO. 25.

Three commercial preparations of tapioca, two of sago, one sample of pearled barley, and one of rice were selected for this experiment. No attempt was made to free the starch from cellulose or other substance, the materials as purchased being simply cooked on a water bath until soft. When the starch was digested the proportion of malt extract to starch was not definitely fixed, since no attempt was made to secure other than qualitative results. When tested with iodine, it was found that the tapioca and sago digested in one stage as did potato and arrowroot starch (see Table 1). Rice and barley showed distinctly the two stages found in the digestion of corn and wheat starches (see Table 1).

These results, therefore, confirm the conclusions from earlier experiments that the starches produced in the cereal grains differ from those in roots and stems in that they contain rose amylose, and hence are more difficult of complete digestion unless cooked for a long time.

CORNSTARCH v. WHEAT STARCH.

The experiments here reported have shown that, in so far as there is a difference, cornstarch digests more rapidly than wheat starch and the digestibility of both is alike increased by long-continued cooking. The housekeeper's rule that cornstarch should be cooked longer than wheat starch seems to be founded on the fact that cornstarch pastes, unless cooked 30 to 40 minutes, have a peculiar flavor, disagreeable to most persons, which is not noticed with wheat and other starches. Efforts were made to learn the cause of this flavor, but without success, and more work is desirable on this point. It seems probable that the flavor is due to an impurity in the commercial starch which either evaporates or is decomposed on long-continued cooking.

From the standpoint of flavor, therefore, cornstarch should be cooked 30 to 40 minutes. Moreover, if Pawlow^a is right in concluding that foods which please the palate are more easily digested than those which do not, it may be true that the long-continued cooking increases the digestibility of the cornstarch under natural conditions more than would be indicated by the artificial digestion experiments here reported.

DEDUCTIONS AND CONCLUSIONS.

In applying the results of these experiments it must be remembered that in general the starches used in the experiments had been separated from the other substances with which they are ordinarily combined in foods. Hence, in cooking starchy foods, such as potatoes, it is necessary to consider the time required for the heat to penetrate to the center of the mass, and to remember that the effect of cooking potatoes, for instance, includes changes in the cellulose present as well as in the

^aThe Work of the Digestive Glands. London, 1902.

starch. Furthermore, the relative digestibility of two starchy foods may depend on other factors than the starch content. For instance, the fact that rice is considered easier of digestion or better tolerated than potatoes, an opinion which seems to be based very largely on experience gained in invalid dietetics, is, if true, probably due to the relative digestibility of other constituents than the starch in the foods, since rice starch, as shown by the experiments here reported, contains the slowly digesting rose amylose not found in potato starch. It must be remembered, further, that the digestion experiments reported were made by artificial rather than natural methods, and that it is hardly possible in laboratory experiments to duplicate all the conditions present in natural digestion.

Lee,^a among others, has given reasons against drawing conclusions from test-tube experiments with regard to the limits of digestion. He found that when a dialyzer was used to remove the products of diastase action as they were formed, digestion was carried much further than under usual test-tube conditions. However, such objections are not so applicable where the results sought are only comparative, as was the case in the present work. As suggested earlier (see p. 28), it is probable that rose amylose would have been found to digest more rapidly had a dialyzer been employed, but such a modification would also aid the digestion of blue amylose, and it is probable that the ratio between the rates of digestion of the two would not have been much altered. However, it is reasonable to suppose that there may be physiological factors in natural digestion which were not present in these experiments, which would alter the relative results obtained from laboratory tests.^b Bearing in mind these limitations, it seems fair to draw the following conclusions from the experimental evidence reported with potato, arrowroot, tapioca, sago, wheat, corn, rice, and barley starches.

Three substances are found in raw starch grains, which are designated in this bulletin according to the color they give with iodine—blue amylose, red amylose, and rose amylose.

Blue amylose constitutes the entire inside of the starch grains of potato, arrowroot, tapioca, and sago and 90 per cent or more of the inside of the cereal starches studied, namely, wheat, corn, rice, and barley, and is identical with the substance called granulose or β -amylose by other investigators. It gives a blue color with iodine and in the solid form found in raw starch it is digested slowly because of its density. It takes up water at 60° to 80° C. and forms the sticky colloidal substance known as starch paste, in which form it is very easily digested. Long boiling, at least to the extent of 3 hours, does not make it more quickly digestible.

^a Jour. Physiol., 11 (1890), p. 226.

^b See the result of Harcourt's work, p. 17.

Red amylose constitutes the outer layer of the starch grains. It gives a red color with iodine and is more difficult of digestion or change in water than blue amylose. The presence and the density of this layer hinders, though it does not prevent, the digestion of raw starch grains. When starch paste is made without boiling the red amylose layer stretches, though it does not break, and in this condition is easily permeable and does not interfere with the more rapid digestion of the inner portions of the grains. When starch paste is boiled this layer breaks and a more homogeneous, though not more digestible, paste results.

Rose amylose forms about 10 per cent of the inside of cereal starches and is not found in potato, arrowroot, tapioca, and sago starches. It gives an old-rose color with iodine and shows a greater affinity for the iodine than the blue amylose, taking the color sooner and retaining it longer. It digests more slowly than either blue or red amylose, and hence it is fair to conclude that the cereal starches are not as readily digested as the other starches studied. Rose amylose is slowly changed by cooking to the blue amylose form, hence cereal-starch pastes are made somewhat more easily digestible by cooking them for several hours.

There is a fourth substance not found in natural starch grains which has been frequently confused with red and with rose amylose. It is formed as a reversion product from solutions of starch and has been designated reverted amylopectin by Syniewski. It is found in the skin that forms on a starch paste exposed to dry air. It does not stain with iodine and is more difficult of solution and of digestion than any of the amylose forms of starch.

Raw starch, as shown by the experiments reported, digests very much more slowly than the starch in the forms of a paste.

Starch paste made below the boiling temperature of water is as easy to digest as that which has been boiled a few minutes, though it is not as homogeneous.

Potato, arrowroot, and probably tapioca and sago starch pastes are not made more easily digestible by long-continued cooking. On the other hand, the cereal starches are made more easily digestible by long cooking, though the change occurs very slowly and perhaps the increased digestibility is not sufficiently great to justify the trouble, under ordinary circumstances at least, for separated starch such as is used in cookery. However, in the case of starch still inclosed in cellulose cells, as in many starchy foods, the long-continued cooking may be necessary. The commercial preparations of cornstarch require 30 to 40 minutes' cooking because of the improvement in flavor which results.

Skin formation as well as lumps should be avoided in cooking starch—the latter contain raw starch, the former reverted amyloextrin, and both are very slow of digestion.

The selection of potato starch instead of corn or wheat starch for thickening sauces, in accordance with the custom of French cooks, is rational, since it contains no rose amylose and so forms a clearer and more digestible sauce, and since it does not require 40 minutes' boiling for improvement in flavor, as is the case with cornstarch.

Increasing the proportion of diastase to starch in artificial digestion experiments markedly hastens the digestion of both blue and red amylose. It would appear, therefore, that eating starchy foods slowly, which would of course increase the proportion of saliva and ptyalin to a given quantity of starch, would be of more value from the standpoint of digestion than would any cooking of starch beyond the stage of paste formation.

[Bull. 202]



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